SCALE-DEPENDENT CLASSIFICATION OF XERIC LIMESTONE PRAIRIES: ANNUAL OR PERENNIAL GRASSLANDS?[1]

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ABSTRACT

Xeric limestone prairies (XLPs) are herbaceous plant communities that occur on shallow rocky calcareous soils from Missouri and Pennsylvania south to Arkansas and Georgia (U.S.A.). There has been considerable confusion regarding the classification of XLPs due to their similarity with limestone cedar glades (LCGs), an edaphic climax community type restricted to unglaciated southeastern United States. Although C_4 perennial grasses typically are the dominant taxa in XLPs, portions of sites with extremely shallow soils (≤ 0.1 m) are typified by local dominance of *Sporobolus vaginiflorus* (Torr. ex Gray) Alf. Wood, a C_4 summer annual grass that is the characteristic dominant in LCGs. In this study, we assess the relative importance of C_4 perennial grasses versus *S. vaginiflorus* in XLP community types identified in Kentucky over a range of scales. We then use these data to analyze variability in XLP vegetation and physical environmental conditions and to further compare XLPs with LCGs. *Sporobolus vaginiflorus* had high frequencies in many of the fine-scale community types (0.01 and 0.1 m^2) identified in this study. However, dominance of C_4 perennial grasses (particularly *Schizachyrium scoparium* (Michx.) Nash) in all 12 of the community types identified at the largest scale (100 m^2) is indicative of the relatively small areal extent of extremely shallow-soiled regions in XLPs. XLPs also differ from LCGs in that the former generally lack early-stage primary successional community types dominated by cryptograms and/or C_3 annual forbs. Thus, the results of our study suggest that the total range of environmental conditions and the variety and extent of plant community types present in a site should be considered when classifying the vegetation of calcareous rock outcrop communities in the eastern United States.

Key words: cedar glades, community classification, rock outcrop, scale, xeric limestone prairies.

Herbaceous plant communities developed on shallow rocky calcareous soils are broadly distributed in the Eastern Deciduous Forest region (sensu Braun, 1950) in the eastern United States. As is the case in many other types of rock outcrop vegetation, species composition and fine-scale structure in calcareous rock outcrop communities are strongly dependent on local physical environmental conditions, particularly soil depth (e.g., Quarterman, 1948; Skinner, 1979; Somers et al., 1986; Ver Hoef et al., 1993; Rollins, 1997; Baskin & Baskin, 1999). Consequently, classification and description of these plant communities may be affected significantly by the scale at which community sampling is conducted and the heterogeneity of physical environmental conditions within sites. In this study, we consider the effect(s) of grain (i.e., quadrat size) on the classification of species-rich calcareous grasslands known as xeric limestone prairies (XLPs) (sensu Baskin et al., 1994; Baskin & Baskin, 2000; Lawless, 2005).

XLPs are distributed from Missouri (Nelson & Ladd, 1983; Baskin & Baskin, 2000) and Pennsylvania (Laughlin & Uhl, 2003) south to Arkansas (Keeland, 1978; Baskin & Baskin, 2000) and Georgia (DeSelm, 1993). Baskin et al. (1994) and Baskin and Baskin (2000) described these herbaceous communities as C_4 perennial grasslands dominated by *Schizachyrium scoparium* (Michx.) Nash and/or *Bouteloua curtipendula* Torr. However, transitions in dominance from C_4 perennial prairie grasses (*S. scoparium*, *Sorghastrum nutans* (L.) Nash, *Andropogon gerardii* Vitman, and *B. curtipendula*) to C_4 annual grasses (*Sporobolus* R. Br. spp.) often occur in response to decreased soil depths (Ver Hoef et al., 1993; Baskin & Baskin, 2000; Rhoades et al., 2004). Dominance of *Sporobolus vaginiflorus* (Torr. ex Gray) Alf. Wood in the shallow-soil regions of some XLP sites has resulted in confusion of this vegetation type with limestone cedar glades (LCGs) (sensu Baskin & Baskin, 1999, 2000, 2003, 2004), an edaphic climax vegetation type in which the C_4 annual grass *S. vaginiflorus* is the characteristic dominant (Quarterman, 1948; Somers et al., 1986; Rollins, 1997; Baskin & Baskin, 1999).

In this study, we determined the effect of grain on the classification and description of XLP vegetation in

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the Interior Plateau ecoregion in Kentucky (sensu Woods et al., 2002). We assess the relative importance of C_4 perennial grass species versus *Sporobolus vaginiflorus* in XLP community types identified in this study for comparison with XLP and LCG community types described in other studies. Additional biotic variables and physical environmental conditions also are considered as potential sources of variability within and among XLP sites and between XLPs and LCGs. Our research affords insight into the primary source(s) of variability within and among XLPs and identifies key compositional and structural differences between XLPs and LCGs, thus facilitating classification of these vegetation types.

This study focused on XLPs in Kentucky, because (1) numerous XLP sites occur in the state, (2) many of these XLPs are owned and/or managed by state agencies and/or conservation organizations, thus affording relatively easy access, and (3) quantitative vegetation data are lacking for the vast majority of sites in the state. It should also be noted that the presence of both XLPs and LCGs in Kentucky has resulted in considerable confusion regarding the classification of herbaceous vegetation associated with calcareous rock outcrops in this area (Baskin et al., 1994).

METHODS

SAMPLING

In July through October of 2002 and 2003, the vegetation of 18 XLPs in the Interior Plateau ecoregion in Kentucky (see Table 1 for sample site locations) was sampled using a nested quadrat sampling design adapted from Peet et al. (1998) (0.01-, 0.1-, 1-, 10-, and 100-m^2 quadrats). Presence of all nonwoody vascular plant species was recorded in the 0.01- to 10-m^2 quadrats. Each taxon present in the largest quadrat (100-m^2 sampling module) was assigned to one of 10 cover classes. Soil depth was recorded to the nearest centimeter in the four corners of all modules, and soil samples were collected from the top 25 cm of soil in the same locations. Soil samples from each module were composited and submitted to the University of Kentucky Soil Testing Laboratory for the following analyses: pH, buffered pH, texture, water holding capacity, percent organic matter, total nitrogen, cation exchange capacity (total and individually for K, Ca, Mg, and Na), base saturation, and concentrations of P, K, Ca, Mg, Zn, Cu, Mn, Na, Fe, and Al. Three measurements of slope (%) and aspect of slope (in degrees east of true north) were collected for each module using a compass and clinometer, respectively, and an average was calculated for each parameter. The average aspect of slope (Φ) for each module then was used to calculate a corresponding heat load index (HLI) using the following equation: HLI = $(1 - \cos(\Phi - 45))/2$.

Table 1. County and ecoregional locations of the 18 xeric limestone prairies sampled in Kentucky. Ecoregions follow Level IV ecoregions of the Interior Plateau (Level III ecoregion; sensu Woods et al., 2002).

	Site	County	Ecoregion
1	Fort Knox Military Reservation 1	Hardin	Knobs-Norman Upland
2	Fort Knox Military Reservation 2	Hardin	Knobs-Norman Upland
3	Cedar Creek Farms	Hardin	Knobs-Norman Upland
4	Scudder Glade	Hardin	Knobs-Norman Upland
5	Hardin Co. Cedar Glade	Hardin	Knobs-Norman Upland
6	Muldraugh's Barren	Hardin	Knobs-Norman Upland
7	Mixed Grass Barrens	Larue	Knobs-Norman Upland
8	Spalding Glade	Larue	Knobs-Norman Upland
9	Thompson Creek Glade	Larue	Knobs-Norman Upland
10	Pine Creek Barrens	Bullitt	Outer Bluegrass
11	Crooked Creek Barrens 1	Lewis	Outer Bluegrass
12	Crooked Creek Barrens 2	Lewis	Outer Bluegrass
13	Grayson Co. Barren	Grayson	Crawford-Mammoth Cave Uplands
14	Knight's Barren	Hardin	Crawford-Mammoth Cave Uplands
15	Lapland Barrens	Meade	Crawford-Mammoth Cave Uplands
16	Lapland Road Barrens	Meade	Crawford-Mammoth Cave Uplands
17	Logan Co. Glade	Logan	Western Pennyroyal Karst Plain
18	Logan Co. Barrens	Logan	Western Pennyroyal Karst Plain

CLASSIFICATION AND ORDINATION

The flexible beta linkage agglomerative clustering method in PC-ORD (MJM Software Design; McCune & Mefford, 1999) was used to identify community types over the range of spatial scales sampled. A beta value of −0.25 and Sorensen's distance measure were used in all analyses. Indicator species analysis was used to determine the optimal number of groups at each scale via selection of the group number with the lowest average *P* value (Dufrêne and Legendre, 1997).

Nonmetric multidimensional scaling (NMS) (Kruskal, 1964; Mather, 1976) was used to determine variability in community structure at the 100-m^2 scale and to investigate potential sources of variability. A random starting configuration and Sorensen's distance measure were used in the analysis of ground-layer cover class data, which included 40 runs with real data and 50 runs with randomized data (PC-ORD; MJM Software Design; McCune & Mefford, 1999). Abiotic environmental data and cover class data from the primary matrix were entered into a second matrix for calculation of coefficients of determination (r^2) with ordination axes. Only variables with an r^2 value greater than or equal to 0.35 were included in joint plots.

RESULTS

CLUSTER ANALYSIS

0.01-m^2 Community types

Of 174 0.01-m^2 quadrats sampled, 159 contained one or more individuals and were included in cluster analysis. Four community types were identified at the 0.01-m^2 scale, and percent occurrence data resulted in only four characteristic taxa (% occurrence ≥ 30), all of which are graminoids (see summary of characteristic taxa in Table 2) (full analysis of community types at each of five scales is available from the authors by request). Three taxa, *Schizachyrium scoparium*, *Sporobolus vaginiflorus*, and *Carex crawei* Dewey ex Torr., were characteristic in two community types, and *Sorghastrum nutans* was a characteristic taxon in a single community type. The *S. scoparium–S. vaginiflorus* community type contained more quadrats (48) and occurred in more sites (15) than any other community type. The *S. vaginiflorus–C. crawei* community type contained 46 quadrats and occurred in 14 of 18 sites. The community type present in the smallest number of sites (8) and quadrats (22) supported no characteristic taxa.

0.1-m^2 Community types

Of 174 0.1-m^2 quadrats, 173 contained one or more individuals and were included in cluster analysis. Ten community types were identified at the 0.1-m^2 scale, and percent occurrence data resulted in a total of 19 characteristic taxa (% occurrence ≥ 40) among these community types. *Schizachyrium scoparium* was a characteristic taxon in six of these community types, more than any other taxon, and was followed by *Sporobolus vaginiflorus* (4) and *Carex crawei* (3). Eight taxa had a percent occurrence greater than or equal to all other taxa in one or more community types, including *S. scoparium* (4 community types), *S. vaginiflorus* (2), *Andropogon gerardii* (1), *Sorghastrum nutans* (1), *C. meadii* Dewey (1), *C. crawei* (1), *Ruellia humilis* Nutt. (1), and *Rosa carolina* L. (1). The *S. scoparium–S. vaginiflorus–Echinacea simulata* McGregor–*Hedyotis nigricans* (Lam.) Fosberg community type and the *S. vaginiflorus–Heliotropium tenellum* Torr.–*Hypericum dolabriforme* Vent. community type occurred in the largest number of sites (9). The *C. crawei–S. scoparium–S. vaginiflorus–R. humilis* community type was represented in the largest number of quadrats (40).

1-m^2 Community types

All 174 of the 1-m^2 quadrats sampled contained one or more individuals and were included in cluster analysis. Ten community types were identified at the 1-m^2 scale, and percent occurrence data resulted in a total of 39 characteristic taxa (% occurrence ≥ 50) among these community types. *Schizachyrium scoparium* was a characteristic taxon in nine of 10 community types and was followed by *Sporobolus vaginiflorus* (6 community types), *Echinacea simulata* (5), *Euphorbia corollata* L. (5), *Physostegia virginiana* Benth. (5), *Sorghastrum nutans* (4), and *Ruellia humilis* (4). *Schizachyrium scoparium* had a percent occurrence greater than or equal to all taxa in five community types. Other taxa with a percent occurrence greater than or equal to all taxa in two or more community types included *E. simulata* (4 community types) and *S. vaginiflorus* (2). The *S. scoparium–E. simulata–S. vaginiflorus* community type occurred in the most sites (8) and was represented in the largest number of quadrats (51).

10-m^2 Community types

Twelve community types were identified at the 10-m^2 scale, and percent occurrence data resulted in a total of 73 characteristic taxa (% occurrence ≥ 60) among these community types. *Schizachyrium scoparium* was a characteristic taxon in all 12 community types. Only eight additional taxa were characteristic in seven or more community types, including *Sporobolus vaginiflorus* (8), *Sorghastrum nutans* (8), *Echinacea simulata* (8), *Physostegia virginiana* (8), *Euphorbia corollata* (8), *Ruellia humilis* (7), *Solidago nemoralis* Aiton (7), and *Juniperus virginiana* L. (7). *Schizachyrium scoparium* had a percent occurrence greater than or equal to all other taxa in 8 community types and was followed by *S. vaginiflorus* (4) and *E. simulata* (4). The *S. scoparium–S. nutans–E. simulata–S. vaginiflorus* community type occurred in five sites in the Knobs-Norman Upland ecoregion and was represented in more quadrats (36) than any other community type.

Table 2. Summary of characteristic taxa identified at all five spatial scales (0.01–100 m^2) in XLPs in Kentucky, U.S.A. Taxonomy is in accordance with the United States Department of Agriculture, Natural Resources Conservation Service (2004). All voucher specimens were collected in Kentucky and are deposited at KY. Site localities are in accordance with site numbers listed in Table 1.

Family	Species	Site locale	Date	Specimen ID
Acanthaceae	*Ruellia humilis* Nutt.	17	3 July 2002	*Patrick Lawless s.n.*
Agavaceae	*Manfreda virginica* Salisb.	17	3 July 2002	*Patrick Lawless s.n.*
Alliaceae	*Allium cernuum* Roth	1	25 Aug. 2003	*Patrick Lawless s.n.*
Anacardiaceae	*Rhus aromatica* Aiton	10	14 June 2002	*Patrick Lawless s.n.*
Apocynaceae	*Apocynum cannabinum* L.	4	10 July 2002	*Patrick Lawless s.n.*
Asclepiadaceae	*Asclepias viridiflora* Raf.	8	11 Aug. 2003	*Patrick Lawless s.n.*
Asteraceae	*Ambrosia artemisiifolia* L.	13	26 Aug. 2002	*Patrick Lawless s.n.*
	Brickellia eupatorioides (L.) Shinners	17	3 July 2002	*Patrick Lawless s.n.*
	Coreopsis tripteris L.	17	10 July 2002	*Patrick Lawless s.n.*
	Echinacea simulata McGregor	17	5 July 2002	*Patrick Lawless s.n.*
	Eupatorium altissimum L.	17	3 July 2002	*Patrick Lawless s.n.*
	Helianthus hirsutus Raf.	4	10 July 2002	*Patrick Lawless s.n.*
	Liatris aspera Michx.	4	10 July 2002	*Patrick Lawless s.n.*
	Liatris cylindracea Michx.	11	25 July 2002	*Patrick Lawless s.n.*
	Liatris squarrosa Michx.	10	14 June 2002	*Patrick Lawless s.n.*
	Liatris squarrulosa Michx.	10	20 Sep. 1991	*Barry Dalton s.n.*
	Oligoneuron rigidum var. *glabratum* (E. L. Braun) G. L. Nesom	4	10 July 2002	*Patrick Lawless s.n.*
	Parthenium integrifolium L.	4	10 July 2002	*Patrick Lawless s.n.*
	Silphium pinnatifidum Elliott	9	7 Aug. 2003	*Patrick Lawless s.n.*
	Silphium terebinthinaceum Jacq.	11	25 June 2002	*Patrick Lawless s.n.*
	Silphium trifoliatum L.	14	28 July 1978	*Ray Cranfill s.n.*
	Solidago nemoralis Aiton	5	29 Sep. 2003	*Patrick Lawless s.n.*
	Symphyotrichum laeve (L.) A. Löve & D. Löve	4	10 July 2002	*Patrick Lawless s.n.*
	Symphyotrichum urophyllum (DC.) G. L. Nesom	4	10 July 2002	*Patrick Lawless s.n.*
Boraginaceae	*Heliotropium tenellum* Torr.	17	3 July 2002	*Patrick Lawless s.n.*
	Lithospermuan canescens Lehm.	17	3 July 2002	*Patrick Lawless s.n.*
Caesalpiniaceae	*Cercis canadensis* L.	6	22 Sep. 2002	*Patrick Lawless s.n.*
Campanulaceae	*Lobelia spicata* Lam.	17	5 July 2002	*Patrick Lawless s.n.*
Clusiaceae	*Hypericum dolabriforme* Vent.	17	3 July 2002	*Patrick Lawless s.n.*
Cornaceae	*Cornus drummondii* C. A. Mey.	12	26 July 2002	*Patrick Lawless s.n.*
Cupressaceae	*Juniperus virginiana* L.	6	22 Sep. 2002	*Patrick Lawless s.n.*
Cyperaceae	*Carex crawei* Dewey ex Torr.	6	19 May 2002	*Patrick Lawless s.n.*
	Carex meadii Dewey	17	3 July 2002	*Patrick Lawless s.n.*
	Carex umbellata Schkuhr	6	19 May 2002	*Patrick Lawless s.n.*
	Fimbristylis puberula (Michx.) Vahl	10	14 June 2002	*Patrick Lawless s.n.*
Ebenaceae	*Diospyros virginiana* L.	13	26 Aug. 2002	*Patrick Lawless s.n.*
Euphorbiaceae	*Croton capitatus* Michx.	9	13 June 2002	*Patrick Lawless s.n.*
	Croton monanthogynus Michx.	4	10 July 2002	*Patrick Lawless s.n.*
	Euphorbia corollata L.	10	14 June 2002	*Patrick Lawless s.n.*
Fabaceae	*Desmodium glabellum* DC.	11	25 July 2002	*Patrick Lawless s.n.*
	Galactia volubilis (L.) Britton	17	7 July 2002	*Patrick Lawless s.n.*
	Lespedeza virginica (L.) Britton	17	3 July 2002	*Patrick Lawless s.n.*
	Melilotus alba Medik.	11	3 July 2002	*Patrick Lawless s.n.*
Gentianaceae	*Sabatia angularis* (L.) Pursh	4	10 July 2002	*Patrick Lawless s.n.*
Iridaceae	*Sisyrinchium albidum* Raf.	4	10 July 2002	*Patrick Lawless s.n.*
Lamiaceae	*Blephilia ciliata* Raf.	10	14 June 2002	*Patrick Lawless s.n.*
	Isanthus brachiatus Britton, Sterns & Poggenb.	4	10 July 2002	*Patrick Lawless s.n.*
	Monarda fistulosa L.	17	5 July 2002	*Patrick Lawless s.n.*

Table 2. Continued.

Family	Species	Site locale	Date	Specimen ID
	Physostegia virginiana Benth.	5	6 Aug. 2003	*Patrick Lawless s.n.*
	Pycnanthemum tenuifolium Schrad.	17	5 July 2002	*Patrick Lawless s.n.*
Linaceae	*Linum sulcatum* Riddell	17	3 July 2002	*Patrick Lawless s.n.*
Oleaceae	*Fraxinus americana* L.	13	3 June 2002	*Patrick Lawless s.n.*
Onagraceae	*Gaura filipes* Spach	4	10 July 2002	*Patrick Lawless s.n.*
Poaceae	*Andropogon gerardii* Vitman	4	10 July 2002	*Patrick Lawless s.n.*
	Aristida purpurascens Poir.	10	—	*Julian Campbell s.n.*
	Bouteloua curtipendula Torr.	17	3 July 2002	*Patrick Lawless s.n.*
	Danthonia spicata (L.) P. Beauv. ex Roem. & Schult.	4	18 June 2003	*Rob Paratley s.n.*
	Dichanthelium acuminatum (Sw.) Gould & C. A. Clark	9	13 June 2002	*Patrick Lawless s.n.*
	Dichanthelium sphaerocarpon (Ellis) Gould	17	3 July 2002	*Patrick Lawless s.n.*
	Panicum flexile (Gattinger) Scribn.	4	10 July 2002	*Patrick Lawless s.n.*
	Schizachyrium scoparium (Michx.) Nash	4	10 July 2002	*Patrick Lawless s.n.*
	Sorghastrum nutans (L.) Nash	4	10 July 2002	*Patrick Lawless s.n.*
	Sporobolus compositus Merr.	17	7 July 2002	*Patrick Lawless s.n.*
	Sporobolus vaginiflorus (Torr. ex Gray) Alf. Wood	4	10 July 2002	*Patrick Lawless s.n.*
Polygalaceae	*Polygala verticillata* L.	17	3 July 2002	*Patrick Lawless s.n.*
Ranunculaceae	*Clematis pitcheri* Torr. & A. Gray	17	5 July 2002	*Patrick Lawless s.n.*
Rosaceae	*Potentilla simplex* Michx.	17	5 July 2002	*Patrick Lawless s.n.*
	Rosa carolina L.	14	26 June 1992	*Julian Campbell s.n.*
Rubiaceae	*Galium circaezans* Michx.	4	10 July 2002	*Patrick Lawless s.n.*
	Hedyotis nigricans (Lam.) Fosberg	4	10 July 2002	*Patrick Lawless s.n.*
	Houstonia canadensis Willd. ex Roem. & Schult.	17	3 July 2002	*Patrick Lawless s.n.*
Santalaceae	*Comandra umbellata* Nutt.	10	14 June 2002	*Patrick Lawless s.n.*
Scrophulariaceae	*Agalinis tenuifolia* Raf.	10	8 Sep. 1992	*Julian Campbell s.n.*
	Castilleja coccinea Spreng.	12	25 July 2002	*Patrick Lawless s.n.*
Smilacaceae	*Smilax bona-nox* L.	17	3 July 2002	*Patrick Lawless s.n.*
Ulmaceae	*Celtis tenuifolia* Nutt.	17	3 July 2002	*Patrick Lawless s.n.*
Violaceae	*Viola pedata* L.	17	3 July 2002	*Patrick Lawless s.n.*

100-m² Community types

Forty-one taxa had an average cover value of 3% or greater in one or more community types. Fifteen taxa were dominant (avg. cover ≥ 10%) in one or more community type(s). Six of these 15 taxa were dominant in three or more community types, including *Schizachyrium scoparium* (10 community types), *Sporobolus vaginiflorus* (5), *Sorghastrum nutans* (5), *Echinacea simulata* (5), *Andropogon gerardii* (4), and *Carex crawei* (3). *Schizachyrium scoparium* had the highest average cover in 10 of 12 community types identified in this study and in 20 of 22 other studies of XLPs in the eastern United States for which vegetation data were available (Table 3). *Andropogon gerardii* and *Silphium terebinthinaceum* Jacq. each had the highest cover in one 100-m² community type. *Schizachyrium scoparium* and *S. vaginiflorus* were co-dominant in five of 12 community types, and *S. scoparium* and *S. nutans* were co-dominant in four of 12 community types. Only seven taxa were subdominant in three or more community types. *Andropogon gerardii* was subdominant in seven community types, and six taxa, including *E. simulata*, *C. meadii*, *Hedyotis nigricans*, *S. nutans*, *Juniperus virginiana*, and *Cercis canadensis* L., each were subdominant in three community types.

ORDINATION

Monte Carlo test results were statistically significant ($P \leq 0.02$) for each of the six ordination axes analyzed. The final NMS ordination consisted of 400 iterations of a three-dimensional solution and resulted in final stress equal to 15.33 and instability equal to 0.00829. Percent of variance (equal to cumulative $r^2 \times 100$) collectively explained by the three axes was

Table 3. Summary of dominant taxa in XLPs of the eastern United States. Data (quantitative and qualitative) are organized by Level III ecoregions (sensu Omernik, 1987).

Ecoregion	Dominant taxon	Reference	Data
Ozark Highlands	*Sporobolus neglectus**	Hall, 1955	frequency
	Schizachyrium scoparium	Kucera & Martin, 1957	avg. cover
	Schizachyrium scoparium	Keeland, 1978	avg. cover
	Schizachyrium scoparium†	Skinner, 1979	avg. frequency
	Sporobolus neglectus‡	Skinner, 1979	avg. frequency
	Schizachyrium scoparium	Hicks, 1981	avg. importance value
	Schizachyrium scoparium	Logan, 1992	semi-quantitative
	Schizachyrium scoparium	Ver Hoef et al., 1993	avg. geometric mean of cover
	*Panicum virgatum**	George, 1996	avg. cover
	Schizachyrium scoparium	George, 1996	avg. cover
Eastern Corn Belt Plains	*Schizachyrium scoparium*	Maxwell, 1987	qualitative
Interior River Hills and Lowlands	*Schizachyrium scoparium*	McClain & Ebinger, 2002	avg. cover
	Bouteloua curtipendula	McClain & Ebinger, 2002	avg. cover
	Hedyotis nigricans	McClain & Ebinger, 2002	avg. cover
	Schizachyrium scoparium	Heikens, 1991	avg. cover
Interior Plateau	*Schizachyrium scoparium*	Heikens, 1991	avg. cover
	Silphium terebinthinaceum	Heikens, 1991	avg. cover
	*Schizachyrium scoparium***	Kurz, 1981	avg. frequency
	Schizachyrium scoparium	Braun, 1928	avg. frequency
	Andropogon gerardii	Braun, 1928	avg. frequency
	Schizachyrium scoparium	Baskin & Baskin, 1977	frequency
	Schizachyrium scoparium	DeSelm, 1988	importance values
	Schizachyrium scoparium	DeSelm, 1991	avg. cover
	Schizachyrium scoparium	DeSelm & Webb, 1997	avg. cover
	*Sporobolus clandestinus**	DeSelm & Webb, 1997	avg. cover
	Schizachyrium scoparium	this study	avg. cover
	Andropogon gerardii	this study	avg. cover
	Silphium terebinthinaceum	this study	avg. cover
Ridge and Valley	*Bouteloua curtipendula*	Bartgis, 1993	avg. cover
	Solidago arguta var. *harrisii**	Bartgis, 1993	qualitative
	Monarda fistulosa var. *brevis**	Bartgis, 1993	qualitative
	*Paronychia virginica**	Bartgis, 1993	qualitative
	Schizachyrium scoparium	DeSelm, 1993	avg. cover
	Andropogon gerardii	DeSelm, 1993	avg. cover
	Schizachyrium scoparium	Ludwig, 1999	avg. cover
	Andropogon gerardii	Ludwig, 1999	avg. cover
	Schizachyrium scoparium	Allison & Stevens, 2001	qualitative
	Bouteloua curtipendula	Laughlin & Uhl, 2003	semi-quantitative
Southeastern Plains	*Schizachryium scoparium*	Harper, 1920	qualitative

* Authors and families of taxa that are in this table but do not appear in Table 2 are as follows: *Sporobolus neglectus* Nash (Poaceae), *Panicum virgatum* L. (Poaceae), *Sporobolus clandestinus* Hitchcock (Poaceae), *Solidago arguta* Spreng. var. *harrissii* (E. S. Steele) A. W. Cusick (Asteraceae), *Monarda fistulosa* var. *brevis* Fosber & Artz (Lamiaceae), *Paronychia virginica* L. (Caryophyllaceae).

† Based on frequency data collected in 0.01 and 0.1-m^2 quadrats centered around the rare focal species *Stenosiphon linifolius* (Nutt. ex E. James) Heynh. (Onagraceae).

‡ Based on frequency data collected in 0.01 and 0.1-m^2 quadrats centered around the rare focal species *Penstemon cobaea* var. *purpureus* Pennell (Scrophulariaceae) and *Centaurium texense* (Griseb.) Fernald (Asteraceae).

** Twenty-three of 32 sample sites were located in the Interior Plateau and nine in the Ozark Highlands; however, data were not stratified by site.

82.9%, and the increment r^2 values of the three axes were as follows: 1 = 0.234, 2 = 0.226, and 3 = 0.369. Orthogonality between axis pairs ranged from 97.2% to 99.1%.

Only quadrats from the two sites in the eastern Outer Bluegrass ecoregion (Crooked Creek Barrens sites 1 and 2) had relatively large negative eigenvectors (~ −1) on axis three (Fig. 1), and as a result the

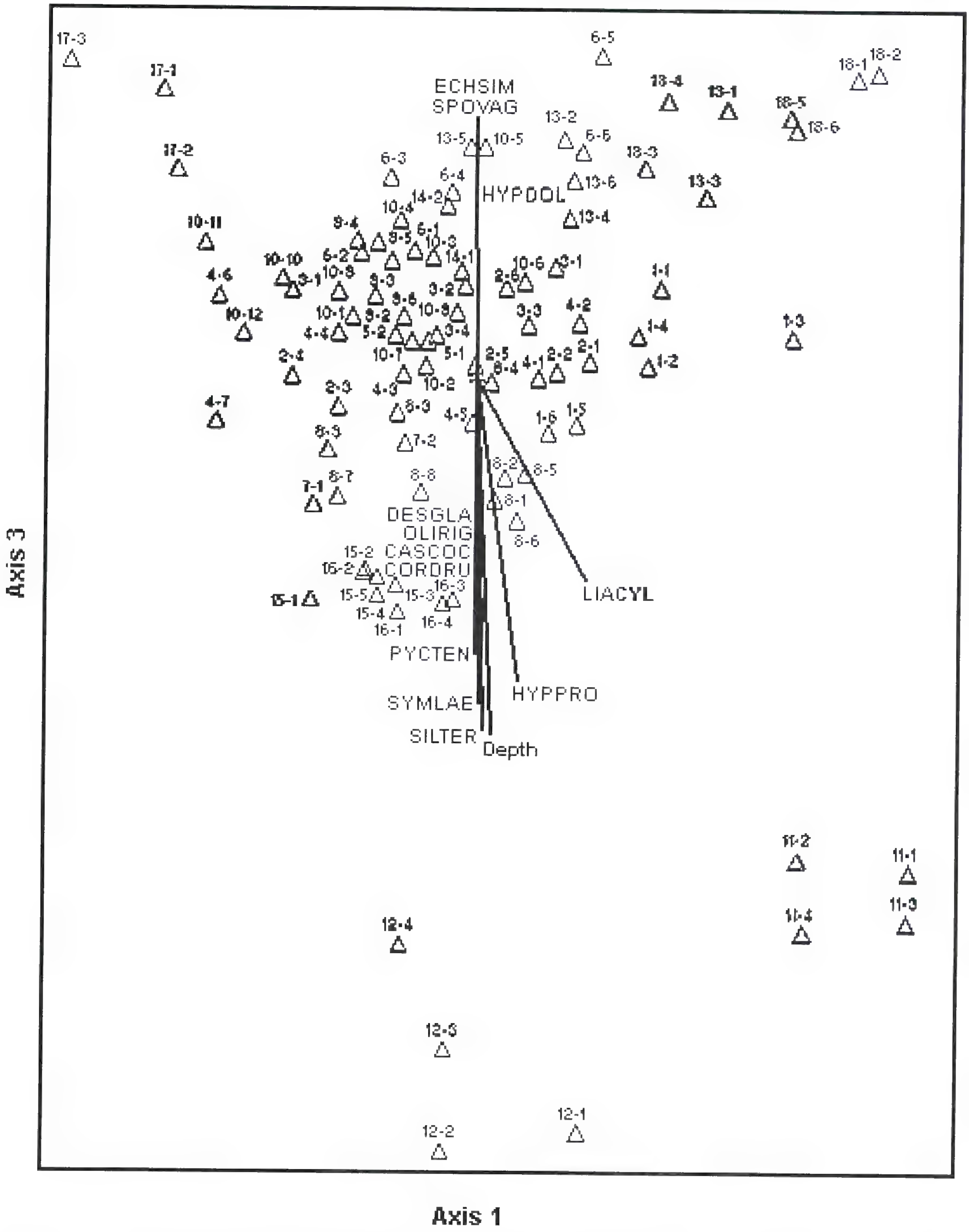

Figure 1. Joint plot (axis 1 vs. 3) including abiotic environmental variables and taxa with r^2 values greater than or equal to 0.35. Each 100-m^2 quadrat (i.e., sample module) is represented by a triangle labeled with site number (from Table 1) followed by module number within site. Taxon codes are formed by the first three letters of the genus and species epithet, respectively. "Depth" symbolizes soil depth.

distances between these quadrats and all others were high. There was a strong negative correlation between soil depth and axis three, and cover of 11 taxa also was correlated (r^2 value ≥ 0.35) with axis three. Cover of *Silphium terebinthinaceum*, *Symphyotrichum laeve* (L.) A. Löve & D. Löve, *Hypericum prolificum* L., *Pycnanthemum tenuifolium* Schrad., *Liatris cylindracea* Michx., *Cornus drummondii* C. A. Mey., *Castilleja* *coccinea* Spreng., *Oligoneuron rigidum* var. *glabratum* (E. L Braun) G. L. Nesom, and *Desmodium glabellum* DC. was correlated negatively with axis three, and cover of *Sporobolus vaginiflorus* and *Echinacea simulata* was correlated positively with this axis. Axis three eigenvectors of quadrats from Logan County Glade and Logan County Barrens were large (≥ 0.59). Only quadrats from Pine Creek Barrens had relatively large positive eigenvectors (≥ 0.6) on axis two. Cover of *Carex crawei*, *Aristida purpurascens* Poir., *Euphorbia corollata*, *Symphotrichum urophyllum* (DC.) G. L. Nesom, and *L. squarrosa* Michx. was correlated positively with axis two.

Discussion

Results of this study confirm that XLPs in Kentucky are C_4 perennial grasslands as described by Baskin et al. (1994) and Baskin and Baskin (2000). Despite *Sporobolus vaginiflorus* being a dominant taxon (avg. cover ≥ 10%) in five of 12 100-m^2 community types, collective average cover of C_4 perennial grasses (primarily *Schizachyrium scoparium*, *Sorghastrum nutans*, and *Andropogon gerardii*) exceeded cover of *S. vaginiflorus* in all 12 100-m^2 community types. *Schizachyrium scoparium* had the highest average cover in 10 of 12 100-m^2 XLP community types identified in this study and was dominant (i.e., had the highest cover, frequency, or importance value) in 17 of 19 studies conducted in XLPs in other regions of the eastern United States. Thus, *S. scoparium* should be considered the characteristic dominant taxon in XLPs of the eastern United States.

However, *Sporobolus vaginiflorus* was a characteristic taxon in the majority of community types identified in this study at scales less than 100 m^2. In one of four 0.01-m^2 community types and two of 10 0.1-m^2 community types, *S. vaginiflorus* was the only characteristic grass taxon, thus indicating local dominance of this taxon in a considerable number of sites. This finding is consistent with those of Hall (1955), Kucera and Martin (1957), Skinner (1979), Hicks (1981), Nelson (1985), Logan (1992), and Ver Hoef et al. (1993) on XLPs in the Ozarks, which were summarized by Baskin and Baskin (2000). Therefore, when considered at fine spatial scales, portions of some XLP sites fit the physiognomic description of cedar glades provided by Baskin and Baskin (2003).

Sporobolus vaginiflorus and *Schizachyrium scoparium* were both characteristic in the 0.01-m^2 and 0.1-m^2 community types identified in this study that contained the largest number of quadrats. Therefore, *S. vaginiflorus* is not necessarily confined to portions of sites in which perennial grasses are absent, which typically have extremely shallow (≤ 0.1 m) soil depths, and apparently is capable of competing with these grasses over a range of local environmental conditions. Frequencies of both *S. vaginiflorus* and C_4 perennial grasses (*Bouteloua curtipendula* and/or *Sorghastrum nutans*) also were high in the shallow-soil community types ("rocky glade" and "shallow soil glade") on Gasconade Dolomite described by Ver Hoef et al. (1993). In addition, high frequency of co-occurrence of *S. vaginiflorus* and *Andropogon virginicus* L./*S. scoparium* (uncertainty resulting from spring sampling) was observed in one of the 14 0.1-m^2 LCG community types identified by Rollins (1997).

In the XLPs sampled in Kentucky, soil depth and *Sporobolus vaginiflorus* cover also were significant sources of variability at the largest grain (100 m^2). However, 13 of the 17 taxa with r^2 values greater than or equal to 0.35 were herbs. This phenomenon is due largely to the small number of characteristic graminoid taxa and their high percent occurrence values in this vegetation type. Thus, the patchy distribution of herbaceous taxa is largely responsible for differences in species composition among sites, because the dominant graminoids are present in the vast majority of sites. This patchy distribution pattern most likely is attributable to the rarity of this vegetation type at the landscape scale and small area of XLPs in comparison with the regionally dominant deciduous forests and agricultural lands (Lawless et al., 2004). Therefore, colonization, extinction, and factors that affect such processes (e.g., site area, distance from nearest site, regional species pools) strongly influence species composition in XLPs and are primary sources of variability in this vegetation type throughout its range in the eastern United States.

COMPARISON OF XLPs AND LCGs AND THEIR CLASSIFICATION

The C_4 annual grass *Sporobolus vaginiflorus* is an important component of both XLP and LCG community types. In XLPs, *S. vaginiflorus* is locally dominant in areas with extremely shallow soils (≤ 0.1 m), and it is abundant in areas of greater soil depth, where *Schizachyrium scoparium* (or other C_4 perennial grasses) is the dominant taxon. Lack of dominance of *S. vaginiflorus* in any of the 12 100-m^2 community types identified in this study suggests that extremely shallow soils are not areally extensive in XLPs. Conversely, dominance of *S. vaginiflorus* in LCG community types identified over a range of scales, from 0.01 to 100 m^2 (Quarterman, 1948; Somers et al., 1986; Rollins, 1997), is indicative of the pervasiveness of extremely shallow soils in the LCG vegetation type. Therefore, average soil depth and the range of soil depths in XLPs and LCGs are considerably different.

XLPs and LCGs differ not only with respect to their characteristic dominant taxa and soil depth characteristics but also in the different community types that occur in each kind of vegetation and in the species composition of these community types. Although mosses, lichens, blue-green algae (*Nostoc commune* Vaucher), and macrobiotic crusts were observed in some sites sampled in this study, they were not observed in high frequency. Conversely, early-stage primary successional community types dominated by cryptograms are common in LCGs (Quarterman, 1948; Somers et al., 1986; Rollins, 1997; Baskin & Baskin, 1999), as well as many other rock outcrop vegetation types in the eastern United States, including alvars (Catling & Brownell, 1999), granite rock outcrops (Oosting & Anderson, 1939; Burbanck & Platt, 1964; Shure & Ragsdale, 1977; Shure, 1999), sandstone rock outcrops (Perkins, 1981), rock ledges (Winterringer & Vestal, 1956), and high-elevation rock outcrops of various substrates (Wiser & White, 1999). In addition, XLPs generally lack the C_3 annual forb-dominated seral stages that typically occur in LCGs subsequent to soil genesis by cryptogram community types (Quarterman, 1948; Somers et al., 1986; Rollins, 1997; Baskin & Baskin, 1999). These C_3 annual forb-dominated community types are restricted to areas of LCGs with very thin soils over bedrock, and they are the primary habitat for a considerable number of taxa (e.g., *Leavenworthia* Torr. spp.) endemic or near endemic to LCGs of the southeastern United States (sensu Baskin & Baskin, 1999, 2003). Thus, absence or infrequency of these physical environmental conditions and corresponding C_3 annual forb-dominated community types in XLPs may explain the low frequency of occurrence of LCG endemics and/or near endemics in XLPs of the eastern United States (Lawless, 2005).

Community types identified in this study represent compositional and structural variation within and among XLP plant communities. Some XLP community types identified in this study and in others (particularly those dominated by *Sporobolus vaginiflorus*) closely resemble those present in LCGs of the southeastern United States. However, distinct differences are apparent between XLPs and LCGs when the total range of environmental conditions and the variety and extent of plant community types present are considered. Prevalence of C_4 perennial grass–dominated community types, infrequency or absence of early stage primary successional seres composed of cryptograms and/or C_3 annual forbs, and extremely variable soil depths ($<$ 0.01 to $>$ 1 m) are all characteristics of XLPs that distinguish them from LCGs and, thus, should be used in any classification system involving these calcareous rock outcrop vegetation types.

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